CLAIMS

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An apparatus for welding by depositing drops of molten metal at the end of a consumable welding wire into a weld puddle comprising:

a power source having a current output in electrical communication with the welding wire;

feedback means for providing a real-time signal indicative of the heat input to each drop; and

a controller means, coupled to the power source and having a feedback input coupled to the feedback means, for controlling the magnitude of the current provided to the welding wire in response to the heat input to each drop.

2. The apparatus of claim 1, wherein the feedback means includes a signal representative of the output, and the controller means includes means for determining the power delivered to the wire, and for determining when the short is about to clear in response to the power delivered.

3. The apparatus of claim 2 wherein the means for controlling includes means for determining a rate of change of the output power.

4. The apparatus of claim 3 wherein the means for controlling includes means for determining a value V_c defined by $V_c = k*(dp/dt)$, wherein k is a scalar and dp/dt is the derivative of the power, and wherein the controller includes means for comparing V_c to a threshold.

5. The apparatus of claim 4 wherein the threshold is dependent on at least one of wire feed speed, wire size, or wire type.

6. The apparatus of claim 3 wherein the means for controlling includes means for subtracting a value responsive to the rate of change of the output current from the rate of change of the output power.

7. The apparatus of claim 3 wherein the means for controlling includes means for determining a value V_c defined by $V_c = k1*(dp/dt) - k2*(di/dt)$, wherein k1 is a scalar, dp/dt is the derivative of the output power, k2 is a scalar, and di/dt is the derivative of the output current, and wherein the controller includes means for comparing V_c to a threshold.

8. The apparatus of claim 6 wherein the means for controlling includes means for taking the derivative of a value responsive to the rate of change of the output power less the value responsive to the rate of change of the output current.

9. The apparatus of claim 8 wherein the means for controlling includes means for determining a value V_c defined by $V_c = d/dt(k1*dp/dt - k2*di/dt)$, wherein k1 is a scalar, dp/dt is the derivative of the output power, k2 is a scalar, and di/dt is the derivative of the output current, and wherein the controller includes means for comparing V_c to a threshold.

10. The apparatus of claim 1 wherein the feedback means includes a voltage signal representative of the output voltage and the means for controlling includes means for summing over time a difference between the voltage signal

and a voltage setpoint, and means for controlling the current in response to that sum, whereby the arc length is controlled to a desired length.

11. The apparatus of claim 10 wherein the means for summing sums only over the time when an arc exists.

12. The apparatus of claim 9 wherein the means for controlling further includes means for summing over time a difference between the voltage signal and a voltage setpoint when an arc exists, and means for controlling the current in response to that sum, whereby the arc length is controlled to a desired length.

13. The apparatus of claim 1 wherein the means for controlling includes means for providing a desired mass deposition rate responsive to a wire feed speed and a distance from a tip of the wire to the workpiece.

14. The apparatus of claim 12 wherein the means for controlling includes means for providing a desired mass deposition rate responsive to a wire feed speed and a distance from a tip of the wire to the workpiece.

15. The apparatus of claim 1 wherein the means for controlling includes means for comparing a value responsive to the energy needed to melt a given amount of wire to a value representing the amount of energy delivered in at least a portion of one welding cycle.

16. The apparatus of claim 12 wherein the means for controlling includes means for comparing a value responsive to the energy needed to melt a given amount of wire to a value representing the amount of energy delivered in at least a portion of one welding cycle.

17. The apparatus of claim 16 wherein the means for comparing compares a value responsive to the energy needed to melt a given amount of wire to a value representing the amount of energy delivered in one complete welding cycle.

18. The apparatus of claim 15 wherein the means for controlling includes means for determining the energy needed in accordance with $Q_{req} = k3 * (R_{dep} * (H_m + (T_{drop} - T_{amb}) * C_p) * t_{tot})$, where Q_{req} is the energy needed, k3 is a scalar, R_{dep} is a wire mass deposition rate, H_m is a latent heat of melting for the wire, T_{drop} is the temperature of the molten drop, T_{amb} is the ambient temperature of the wire, C_p is the heat capacity of the wire, and t_{tot} is a cycle length, and the means for controlling includes means for determining the energy delivered in accordance with $Q_{wire} = ((V_{anode} + WF + 3kT/2e) * I + I^2 * l * rho/A)$, where Q_{wire} is the energy delivered, V_{anode} is the anode voltage drop, WF is the work function of the metal comprising the wire, $(3kT/2e)$ is the thermal energy of electrons impinging on the wire, I is the output current, l is the contact tip to arc distance, rho is the resistivity of the wire, and A is the cross sectional area of the wire.

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19. The apparatus of claim 17 wherein the means for controlling includes means for determining the energy needed in accordance with $Q_{req} = k3 * (R_{dep} * (H_m + (T_{drop} - T_{amb}) * C_p) * t_{tot})$, where Q_{req} is the energy needed, k3 is a scalar, R_{dep} is a wire mass deposition rate, H_m is a latent heat of melting for the wire, T_{drop} is the temperature of the molten drop, T_{amb} is the ambient temperature of the wire, C_p is the heat capacity of the wire, and t_{tot} is a cycle length, and the means for controlling includes means for determining the energy delivered in accordance with $Q_{wire} = ((V_{anode} + WF + 3kT/2e) * I + I^2 * l * rho/A)$, where Q_{wire} is the energy

delivered, V_{anode} is the anode voltage drop, WF is the work function of the metal comprising the wire, (3kT/2e) is the thermal energy of electrons impinging on the wire, I is the output current, l is the contact tip to arc distance, rho is the resistivity of the wire, and A is the cross sectional area of the wire.

20. The apparatus of claim 1 wherein the means for controlling includes means for determining a length of stick out.

21. The apparatus of claim 12 wherein the means for controlling includes means for determining a length of stick out.

22. The apparatus of claim 1 wherein the means for controlling includes means for determining the heat input to the wire and comparing the heat input to a predetermined heat level.

23. The apparatus of claim 21 wherein the means for controlling includes means for determining the heat input to the wire and comparing the heat input to a predetermined heat level.

24. The apparatus of claim 22 wherein the means for controlling includes means for summing over time a value representative of I^2*R, where I is the current and R is the resistance of the wire, for a plurality of locations along the wire, and for comparing the sum for the location at the end of the wire to a predetermined heat level.

25. The apparatus of claim 23 wherein the means for controlling includes means for summing over time a value representative of I^2*R, where I is the current and R is the

resistance of the wire, for a plurality of locations along the wire and for comparing the sum for the location at the end of the wire to a predetermined heat level.

26. An apparatus for welding by depositing drops of molten metal at the end of a welding wire into a weld puddle comprising:

a power source having a current output in electrical communication with the welding wire;

a feedback circuit that provides a real-time signal indicative of the heat input to each drop; and

a controller coupled to the power source and having a feedback input coupled to the feedback circuit, for controlling the magnitude of the current provided to the welding wire in response to the heat input to each drop.

27. The apparatus of claim 26 wherein the controller includes a current circuit that derives a signal representative of the current output, and a power circuit that determines the power delivered to the wire, and a clearing circuit that determines when the short is about to clear in response to the power delivered.

28. The apparatus of claim 27 wherein the controller includes a microprocessor.

29. The apparatus of claim 27 wherein the circuits include analog circuits.

30. The apparatus of claim 26 wherein the controller includes a circuit that compares a value responsive to the energy needed to melt a given amount of wire to a value representing the amount of energy delivered in at least a portion of one welding cycle.

31. The apparatus of claim 26 wherein the controller includes a circuit that determines a length of stick out.

32. A method of welding by depositing drops of molten metal at the end of a welding wire into a weld puddle comprising:

providing current to the wire:

providing feedback, in real-time, indicative of the heat input to each drop; and

controlling the magnitude of the current provided to the welding wire in response to the heat input to each drop.

33. The method of claim 32 wherein the step of providing feedback includes providing a signal representative of the output, and the step of controlling includes determining the power delivered to the wire and determining when the short is about to clear in response to the power delivered.

34. The method of claim 33 wherein the step of controlling includes determining a rate of change of the output power.

35. The method of claim 34 wherein the step of controlling includes determining a value V_c defined by $V_c = k*(dp/dt)$, wherein k is a scalar and dp/dt is the derivative of the power, and wherein the controller compares V_c to a threshold.

36. The method of claim 35 wherein the step of controlling includes subtracting a value responsive to the rate of change of the output current from the rate of change of the output power.

37. The method of claim 36 wherein the step of controlling includes determining a value V_c defined by $V_c = k1*(dp/dt) - k2*di/dt$, wherein k1 is a scalar, dp/dt is the derivative of the output power, k2 is a scalar, and di/dt is the derivative of the output current.

38. The method of claim 37 wherein the step of controlling includes taking the derivative of a value responsive to the rate of change of the output power less the value responsive to the rate of change of the output current.

39. The method of claim 38 wherein the step of controlling includes determining a value V_c defined by $V_c = d/dt(k1*dp/dt - k2*di/dt)$, wherein k1 is a scalar, dp/dt is the derivative of the output power, k2 is a scalar, and di/dt is the derivative of the output current.

40, The method of claim 32 wherein the step of controlling includes providing a desired mass deposition rate responsive to a wire feed speed and a distance from a tip of the wire to the workpiece.

41. The method of claim 32 wherein the step of controlling includes comparing a value responsive to the energy needed to melt a given amount of wire to a value representing the amount of energy delivered in at least a portion of one welding cycle.

42. The method of claim 32 wherein the step of controlling includes determining the energy needed in accordance with $Q_{req} = k3 * (R_{dep} * (H_m + (T_{drop} - T_{amb}) * C_p) * t_{tot})$, where Q_{req} is the energy needed, k3 is a sqalar, $(R_{dep}$ is a wire mass deposition rate, H_m is a latent heat of melting for the wire, T_{drop} is the temperature of the molten

drop, T_{amb} is the ambient temperature of the wire, C_p is the heat capacity of the wire, and t_{tot} is a cycle length, and determines the energy delivered in accordance with $Q_{wire} = ((V_{anode} + WF + 3kT/2e) * I + I^2*l*rho/A)$, where Q_{wire} is the energy delivered, V_{anode} is the anode voltage drop, WF is the work function of the metal comprising the wire, $(3kT/2e)$ is the thermal energy of electrons impinging on the wire, I is the output current, l is the contact tip to arc distance, rho is the resistivity of the wire, and A is the cross sectional area of the wire.

43. The method of claim 41 wherein the step of controlling includes determining the energy needed in accordance with $Q_{req} = k3 * (R_{dep} * (H_m + (T_{drop} - T_{amb}) * C_p) * t_{tot})$, where Q_{req} is the energy needed, k3 is a scalar, $(R_{dep}$ is a wire mass deposition rate, H_m is a latent heat of melting for the wire, T_{drop} is the temperature of the molten drop, T_{amb} is the ambient temperature of the wire, C_p is the heat capacity of the wire, and t_{tot} is a cycle length, and determines the energy delivered in accordance with $Q_{wire} = ((V_{anode} + WF + 3kT/2e) * I + I^2*l*rho/A)$, where Q_{wire} is the energy delivered, V_{anode} is the anode voltage drop, WF is the work function of the metal comprising the wire, $(3kT/2e)$ is the thermal energy of electrons impinging on the wire, I is the output current, l is the contact tip to arc distance, rho is the resistivity of the wire, and A is the cross sectional area of the wire.

44. The method of claim 32 wherein the step of controlling includes determining a length of stick out.

45. The method of claim 32 wherein the step of controlling includes determining the heat input to the wire and comparing the heat input to a predetermined heat level.

46. A method of determining the length of stick out, comprising the steps of:

providing an arc voltage setpoint;

comparing the arc voltage setpoint to the arc voltage;

integrating the comparison over time;

summing the integrand with a required mass deposition rate error; and

comparing the sum to known values.

47. A welding controller that determines the length of stick out, comprising:

means for providing an arc voltage setpoint;

means for providing arc voltage feedback;

means for comparing the arc voltage setpoint to the arc voltage, wherein the means for comparing is connected to receive the arc voltage feedback and arc voltage setpoint;

means for integrating the comparison over time, wherein the means for integrating is connected to receive the comparison;

means for summing the integrand with a required mass deposition rate error, wherein the means for summing is connected to receive the integrand; and

means for comparing the sum to known values, wherein the means for comparing is connected to receive sum.